Application of Principal Component Analysis to the Identification of Concealed Explosives

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1. Introduction

Since the disaster of Pan Am flight N739 over Lockerbie, Scotland in December 1988, caused by and explosive device hidden in passenger baggage, the constantly growing threat of terrorists acts and the unauthorized spread of explosives necessitated the development of a system that can reliably and non-intrusively detect the explosives.

Detection of explosives can be achieved based on one of the parameters such as geometry, vapour emissions and elemental compositions. The shape of explosives can be detected with a X-ray imaging system. Since the geometry of explosives can be modified in various shapes such as toys or foods to hide the presence of suspicious object, the presence of a metallic detonating system has to be detected instead. This method has difficulties for the inspectors to find such a small wire in the detonating system even with a high-resolution X-ray system.

One of the best approaches for the identification of explosives involves the detection of major constituents of explosives such as N, O, C, H and Cl. The ability to measure precisely elemental concentrations in an inspected object is absolutely necessary. In recent years, considerable effort has been directed toward detecting the elemental compositions of explosives by means of thermal neutron interrogation, which involves exposing baggage to thermal neutron.

In some case, information on concentration of elements such as N, O, C, H and Cl present in explosives is far from sufficient for a successful inspection system, since these elements are present also in almost all common materials. Although the concentration of nitrogen is good indicator of explosives, the combinations of oxygen, hydrogen and carbon should be considered since some common compounds contain nitrogen. In particular, there are a number of common materials for suitcase or clothes other than explosives which contain nitrogen, such as silk, nylon and acrylic. If the detection system employs simply nitrogen density imaging, a high false-positive rate results due to the presence of innocent nitrogen-containing materials, leading to the necessity of searching an effective computer program packages exploiting the data compression or reduction methods such as principal component analysis (PCA). The aim of this study is to apply the principal component analysis to reduce the probability of false alarm on the determination of the presence of explosives hidden among other innocuous materials.

2. Methods and Results

2.1. Data Set

A sample of 21 explosives was selected as listed in Table 1. Baggage materials such as various plastics or polymeric materials were also selected as well as the possible contents of baggage as non-explosive samples. Some of these non-explosive materials such as nylon, silk and acrylic contain nitrogen which is a key element of explosives.

Table 1. List of the Explosives

TNT	Trinitrontoluene	$C_7H_5N_3O_6$
Comp.B	RDX(60%)+TNT(40%)+Wax	
Comp.C-4	RDX+plasticizer	
HMX	1357trinitro135triazacyclohexane	$C_4H_8N_6O_8$
PETN	Pentaerythritol Tetranitrate	$C_5H_8N_4O_{12}$
RDX	Cyclonite	$C_3H_6N_3O_6$
Tritonal	TNT(80%)+Al(20%)	
NG	Nitro benzene	$C_6H_5NO_2$
DNT	2amino46dinitrotoluene	$C_7H_6N_3O_4$
NT	2-nitrotoluene	$C_7H_7NO_2$
DNA	3,5-dinitroaniline	$C_6H_5N_3O_4$
MNT	mononitrotoluen	$C_7H_7NO_2$
NG	Nitro-glicerine	$C_3H_5N_3O_9$
Tetryl	2,4,6-N-tetranitro-N-methylaniline	$C_4H_6N_7O_6$
EGDN	Ethylene glycol dinitrate	$C_2H_4N_2O_6$
Semtex-H	RDX+PETN+Plasticizer	
Detasheet	PETN+ Plasticizer	
TNB	135Trinitrobenzene	$C_3H_3N_3O_6$
HFB	Hexafluorobenzene	C_6F_6
OFN	Octafluoronaphthalene	$C_{10}H_8F_8$
NQ		$CH_4N_4O_2$

2.2 Principal Component Analysis

Principal components analysis is a well-known technique of multivariate analysis to characterize the variance and co-variance of the variables in a useful way. PCA was first proposed in 1901 by Pearson [1], and developed independently some year later by Hotelling [2], but it was not widely used until the arrival of modern computing technology. Main goal of PCA is to reduce the dimensionality of a data set in which there are a large number of intercorrelated variables, while retaining as much as possible of the information present in the original data. Dimensionality reduction means that data which were originally represented as objects in an n-dimensional variable space are represented as samples in a redefined m-dimensional space (m < n) with minimal loss of information. This reduction is achieved by a linear transformation to a new set of variables, principal component scores, which are uncorrelated, and ordered such that the first few retain most of the variation present in all of the original variables. PCA is a very useful tool in this regard, since the m eigen-vectors or principal components account for the largest amount of variance in the data set and in that sense provide the optimum linear combination of the original variables.

PCA was performed using the software package MATLAB 6.5.0 release 13 installed on a personal computer with a Pentium V Intel processor.

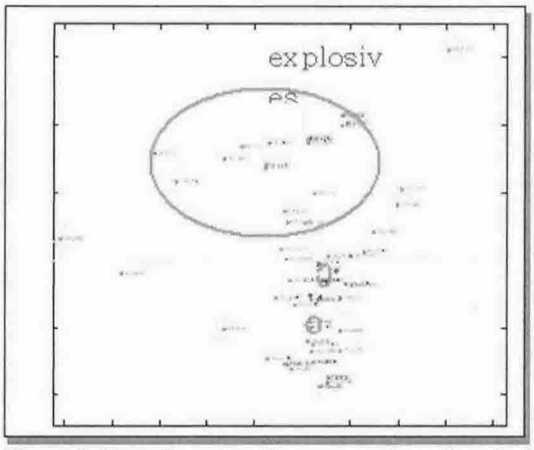

Figure 1. Two-dimensional representation of explosives and non-explosives obtained by the principal component analysis.

The result of the PCA work with elemental information of explosive materials and non-explosive materials is shown in Figure 1. The big circle marked in Figure 1 showed explosives group, although two other explosives were located outside of the circle.

3. Conclusion

The PCA results obtained using the elemental compositions as a data set did not provide a perfect separation of explosive group from the innocuous materials. In addition to that, some innocuous materials containing nitrogen such as silk and acrylic were also found in the explosive group. The used of prompt gamma spectra instead of elemental compositions gave a good sign for the PCA work so far, although the experimental performance was not completed yet.

REFERENCES

[1] K. Pearson, Phils. Mag., 6(2), 559-572 (1901)
[2] H. Hotelling, J. Educ. Psychol., 24, 417-441 (1993)